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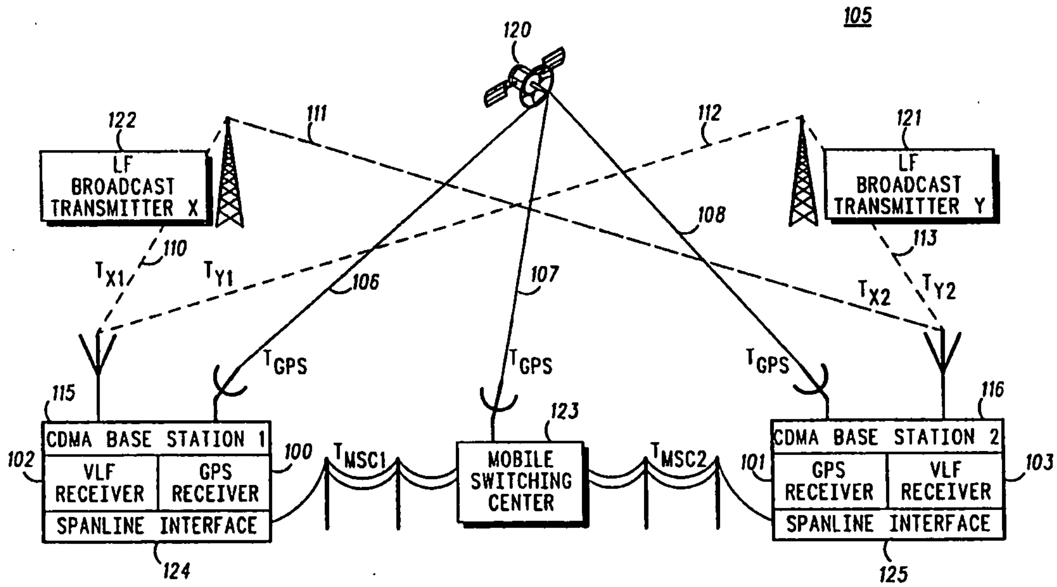

(57) Abstract

A communication system (105) utilizes the global positioning system (GPS) to maintain a high degree of accuracy of synchronization of base-stations (115-116). When the GPS signal (106, 107, or 108) is absent, the communication system (105) employs an alternate signal (110-113), such as a WWVB, LORAN-C, and MSF signal, to provide redundant synchronization of the base-stations (115-116). To achieve the degree of synchronization accuracy provided by the GPS signal (106-108), the communication system (105) characterizes the alternate signal (110-113) by utilizing the GPS signal (106-108) when the GPS signal (106-108) is present. When the GPS signal (106-108) is absent, the characterized alternate signal is then employed such that synchronization of the base-stations (115-116) is transparent to the base-stations (115, 116). Use of the GPS signal (106-108) to characterize the alternate signal (110-113) also allows the characterized alternate signal to provide the same degree of accuracy as that of the GPS signal (106-108).

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APPARATUS AND METHOD FOR PROVIDING SYNCHRONIZATION OF BASE-STATIONS IN A COMMUNICATION SYSTEM

Field of the Invention

The invention relates generally to communication systems, and more specifically to synchronization of base-stations within communication systems.

Background of the Invention

Some communications systems, and particularly a code-division multiple access (CDMA) digital cellular radiotelephone system, require that a fully functional base-station be synchronized within ±3μS of Global Positioning System (GPS) time. In the event of a GPS failure, a ±10μS synchronization window is allowed. The present method of providing the required synchronization is through the use of the GPS satellite network and a GPS receiver. In the event of a GPS failure, a Rubidium oscillator is the present solution to providing redundancy. The use of the Rubidium oscillator for redundancy is a costly alternative for a limited amount of failure protection. A typical Rubidium oscillator will keep a previously synchronized base-station operational for a minimum of nineteen (19) hours, assuming the following:

$$\text{Synchronization Time}_{(\text{minimum})} = (10\mu S - 3\mu S) \,/\, \text{Osc. Accuracy}$$
$$= 7\mu S \,/\, 1\,X10^{-10}$$
$$= 19\ \text{Hrs.}$$

This extremely short time is obtained at an extremely high cost, approximately $4,000 per oscillator. To maintain the required synchronization between CDMA base stations, a central clocking source must be distributed to all base stations in the network. The use of a "Free Running" oscillator will allow a base-station to drift out of synchronization due to tolerances. The greatest difficulty in utilizing a central clocking source is the distribution of that signal with a consistent and predictable propagation delay throughout the network.

Thus a need exists for an apparatus and method that provides reliable redundancy for an extended period of time, while maintaining a cost-effective system design.

Brief Description of the Drawings

FIG. 1 generally depicts a CDMA digital cellular radiotelephone system which may beneficially employ the present invention.

FIG. 2 generally depicts in block diagram form a CDMA synchronization controller in accordance with the invention.

FIG. 3 generally depicts in greater detail GPS time register in accordance with the invention.

Detailed Description of a Preferred Embodiment

The invention provides a redundant cellular base-station synchronization system through the reception of low frequency (LF) band standard and navigational broadcasts such as, inter alia, WWVB, LORAN-C, and MSF. Due to the great coverage of LF broadcasts a central clocking source may be used by an entire cellular network mitigating the limitations associated with asynchronous redundancy schemes such as the "Free Running"

Rubidium oscillator. In most cases a system clock may be synthesized from received LF broadcasts of greater accuracy and stability than that produced by a Rubidium oscillator at a fraction of the cost. The invention utilizes an operational GPS receiver to characterize alternate clocking sources, such as WWVB, LORAN-C, and MSF, by measuring the phase of the signals, and changes in phase and frequency over time. From this characterization the invention determines optimal filter parameters and phase offsets necessary to make the alternate sources usable. The invention not only provides synchronization to a single base-station, but also provides synchronization between base-stations of a communication system.

The invention resides at a cellular base-station 115-116 and is capable of receiving first clocking signals 106-108 and second clocking signals 110-113 from several potential synchronization sources 120-122. The primary clocking source is a GPS receiver 100-101. The redundant sources fall into two (2) categories, LF broadcasts, and spanline clocks. FIG. 1 generally depicts a CDMA digital cellular radiotelephone system which may beneficially employ the present invention. In alternate embodiments, the cellular radiotelephone system may be a time-division multiple access (TDMA) cellular radiotelephone system, or even a paging system requiring synchronization. As depicted in FIG. 1, there is shown low frequency (LF) transmitters 121-122 and a GPS satellite 120 transmitting signals to base-stations 115-116. Within base-stations 115-116, a common hardware platform is used to receive signals 106-108, 110-113 from transmitters, thus providing a high degree of flexibility at a minimal of cost. From these sources the invention synthesizes a high stability system clock, produces a synchronization strobe, and maintains GPS time.

Each base-station 115-116 is coupled to a GPS receivers 100-101. GPS receivers 100-101 receive GPS signals 106-108 which represent a first clocking rate to the system, and are utilized by

base-stations 115-116 for synchronization. Signals 106-108 have a first clocking rate, which in the preferred embodiment is a period of 1 second. Also coupled to each base-station 115-116 is a very low frequency (VLF) receiver which receives precise timing signals 110-113 transmitted by LF transmitters 121-122. Signals 110-113 have a second clocking rate, which in the preferred embodiment is period in the range of 40 ms to 100 ms. However, these signals 110-113 by themselves are not usable, as the propagation delays (TX1, TX2, TY1, TY2) from LF transmitters 121-122 to base-stations 115-116 are unknown. Consequently, GPS signal 106-108 provide greater synchronization accuracy than LF signals 110-113. In accordance with the invention, base-stations 115-116 receive signals from a selected LF transmitter 121-122, determine the clocking rate of the GPS signals 106-108 utilized for synchronization, characterize the second clocking rate of signals 110-113 utilizing the first clocking rate, and employs signals 110-113 having been characterized for synchronization when GPS signals 106-108 are absent. In the preferred embodiment, the characterization of signals 110-113 produces signals having a time-transferred clocking rate. The employment of signals having a time-transferred clocking rate by base-stations 115-116 provides synchronization accuracy as that of GPS signal 106-108. In addition, this approach can maintain network synchronization indefinitely as each base-station 115-116 within the network can synchronize to the same LF transmitter 121-122.

FIG. 2 generally depicts in block diagram form a CDMA synchronization controller in accordance with the invention. In the preferred embodiment, two (2) clocking signals are provided for base-station synchronization by the invention. The first is High Frequency Clock Signal 218 and the second is Synchronization Reference Signal 216, having clocking rates of 19.6608 MHz and a 2 second period respectively.

A Voltage Controlled Crystal Oscillator (VCXO, 210) produces clock signal 218. Clock signal 218 is fed into GPS Time Register 214. Referring now to FIG. 3, FIG. 3 generally depicts in greater detail GPS time register 214 in accordance with the invention. When clock signal enters GPS time register 214, it is digitally divided using Synchronous Counter 304 to produce the reference signal 216. Micro Processor (μP, 206), which in the preferred embodiment is a MC68302, initially synchronizes counter 304 by writing the desired counter value at its preload input. Counter 304 is initialized to this value on receipt of the desired strobe from GPS Receiver 100-101. An Edge Detector 300 is used to synchronize the GPS Receiver 100-101 strobe with clock signal 218.

After the initial counter 304 synchronization is complete, synchronization is maintained by monitoring any counter drift relative to GPS receiver 100-101 strobe. This is accomplished by recording the counter 304 value on receipt of GPS Receiver 100-101 strobe in a Synchronization Register 308. After each GPS strobe, μP 206 reads the contents of register 308 and compares this value with its initial synchronized value. μP 206 will then make any necessary adjustments in the output frequency of VCXO 210 to minimize the measured synchronization error. The output frequency of VCXO 210 is controlled by μP 206 by writing the desired digital value to a Digital to Analog converter (D/A, 208). D/A 208 produces a DC voltage at the control input of VCXO 210, which produces an output frequency proportional to this control voltage. μP 206 implements a digital filter to attenuate phase variations received by GPS receiver 100-101 to produce a stable clock frequency output from VCXO 210.

In a frequency locked condition where the frequency of VCXO 210 is consistently maintaining synchronization, GPS Time Register 214 characterizes the selected redundant synchronization source. This is accomplished using the Dual Port FIFO memory 306 to time stamp strobes received from an

LF receiver 121, 122. FIFO 306 is used to prevent processor latency problems in supporting strobe timing from various LF sources. FIFO 306 records the contents of the counter 304 upon receipt of each strobe from LF receiver 121, 122. μP 206 reads the time stamp information of FIFO 306 and determines the phase and period of the received LF strobes. Edge Detector 302 is used to synchronize the LF receiver 121, 122 strobe with the clock signal 218.

In the event of a GPS network failure, μP 206 will compare the contents of counter 304 with those stored in the FIFO 306 received by the LF receiver 121, 122. μP 206 will adjust the frequency of VCXO 210 by updating the digital value of D/A 208 to maintain the proper phase relationship. The Mobile Switching Center (MSC, 123) will instruct all base-stations 115, 116 in the network to utilize the same LF transmitter, say LF transmitter 122, as a synchronization source via spanline interface 124. This eliminates any drift due to frequency differences between multiple synchronization sources.

A Frequency Locked Loop (FLL) is provided to utilize a recovered spanline clock as a potential redundant synchronization source. In this alternate embodiment, spanline clock may represent a second clocking signal having a second clock rate. The FLL is composed of Reference Multiplexer 200, Prescaler 202, Phase Detector 204, μP 206, D/A 208, VCXO 210, and Loop Divider 212. Multiplexer 200 is a digital multiplexer which selects the desired frequency reference source. Prescaler 202 is a digital divider used to divide the frequency of reference signal 216 to a value that an integer multiple will produce the desired clock signal 218. Phase detector 204 measures the phase difference between the reference signal 216 and the clock signal 218 and produces a digital value proportional to the measured difference that is read by μP 206. μP 206 implements a digital filter to satisfy loop stability requirements and attenuate jitter present on the recovered spanline clock. The output of the digital

filter is fed into the D/A 208 which controls the output frequency of the VCXO 210. The output of the VCXO 210 is fed into loop divider 212 which digitally divides the frequency of clock signal 218 to the same as that at the output of prescaler 202, completing the loop.

Transmissions within the LF radio frequency band are primarily ground based waves and are not affected by changes in the ionosphere level. Therefore, LF radio frequencies (30 kHz to 300 kHz) exhibit only minor phase variations over time. For this reason, the LF band is used primarily for standard time and navigation broadcasts. There are many LF broadcasts (LORAN-C, WWVB) that can be utilized for a central synchronization source.

LORAN-C (LOng RAnge Navigation) is one potential LF synchronization source. It is perhaps one of the most useful in that there are more than fifty (50) transmitters throughout the world providing coverage to most of the northern hemisphere. By using the LORAN-C carrier frequency (100 kHz) as a reference to a frequency locked loop, a system clock with an accuracy of $1X10^{-12}$ can be realized. LORAN-C provides additional redundancy in that it is a Time Division Multiplexed system and multiple transmitters may be monitored using a single LF receiver 121, 122.

Thus, it will be apparent to one skilled in the art that there has been provided in accordance with the invention, an apparatus and method for providing synchronization of base-stations in a communication system that fully satisfies the aims and advantages set forth above.

While the invention has been described in conjunction with specific embodiments thereof, it is evident that many alterations, modifications, and variations will be apparent to those skilled in the art in light of the foregoing description. Accordingly, it is intended to embrace all such alterations, modifications, and variations in the appended claims.

What I claim is:

Claims

1. An apparatus for providing synchronization for a base-station in a communication system, the apparatus comprising:

means for determining a first clocking rate of a first clocking signal utilized for synchronization;

means for characterizing a second clocking rate of a second clocking signal utilizing said first clocking rate; and

means for employing said second clocking signal having said characterized second clocking rate for synchronization when said first clocking signal is absent.

2. The apparatus of claim 1 wherein said first clocking signal provides greater synchronization accuracy than an un-characterized second clocking signal.

3. The apparatus of claim 1 wherein said apparatus provides synchronization between base-stations of a communication system.

4. A base-station in a communication system employing an apparatus for providing synchronization, the base-station comprising:

means for receiving a first clocking signal having a first clocking rate;

means for receiving a second clocking signal having a second clocking rate;

means for synchronizing to said first clocking signal;

means for characterizing said second clocking rate of said second clocking signal utilizing said first clocking rate; and

means for employing said second clocking signal having said characterized second clocking rate for synchronization when said first clocking signal is absent.

5. The base-station of claim 4 wherein said first clocking signal is a global positioning system (GPS) clocking signal.

6. The base-station of claim 4 wherein said second clocking signal is a LOng RAnge Navigation (LORAN) clocking signal.

7. A cellular radiotelephone system requiring synchronization between base-stations, the base-stations being initially synchronized to one another by a global positioning system (GPS) signal having a known clocking rate, the cellular radiotelephone system comprising:

a first base-station employing means for receiving the GPS signal and means for receiving a low frequency (LF) signal transmitted by a LF transmitter, said LF signal having a clocking rate less than said known clocking rate of said GPS signal;

a second base-station employing means for receiving the GPS signal and means for receiving said LF signal transmitted by said LF transmitter;

means, at each base-station, for characterizing each received LF signal utilizing each received GPS signal to produce a signal having a time-transferred clocking rate;

means, when said GPS signal is removed, for employing said signal having a time-transferred clocking rate to provide the required synchronization between said base-stations.

8. The cellular radiotelephone system of claim 7 wherein said GPS signal provides greater synchronization accuracy than an un-characterized LF signal.

9. The cellular radiotelephone system of claim 8 wherein said means for employing further comprises means for employing said signal having a time-transferred clocking rate to provide synchronization accuracy as that of said GPS signal.

10. A method of providing synchronization for a base-station in a communication system, the apparatus comprising:

determining a first clocking rate of a first clocking signal utilized for synchronization;

characterizing a second clocking rate of a second clocking signal utilizing said first clocking rate; and

employing said second clocking signal having said characterized second clocking rate for synchronization when said first clocking signal is absent.

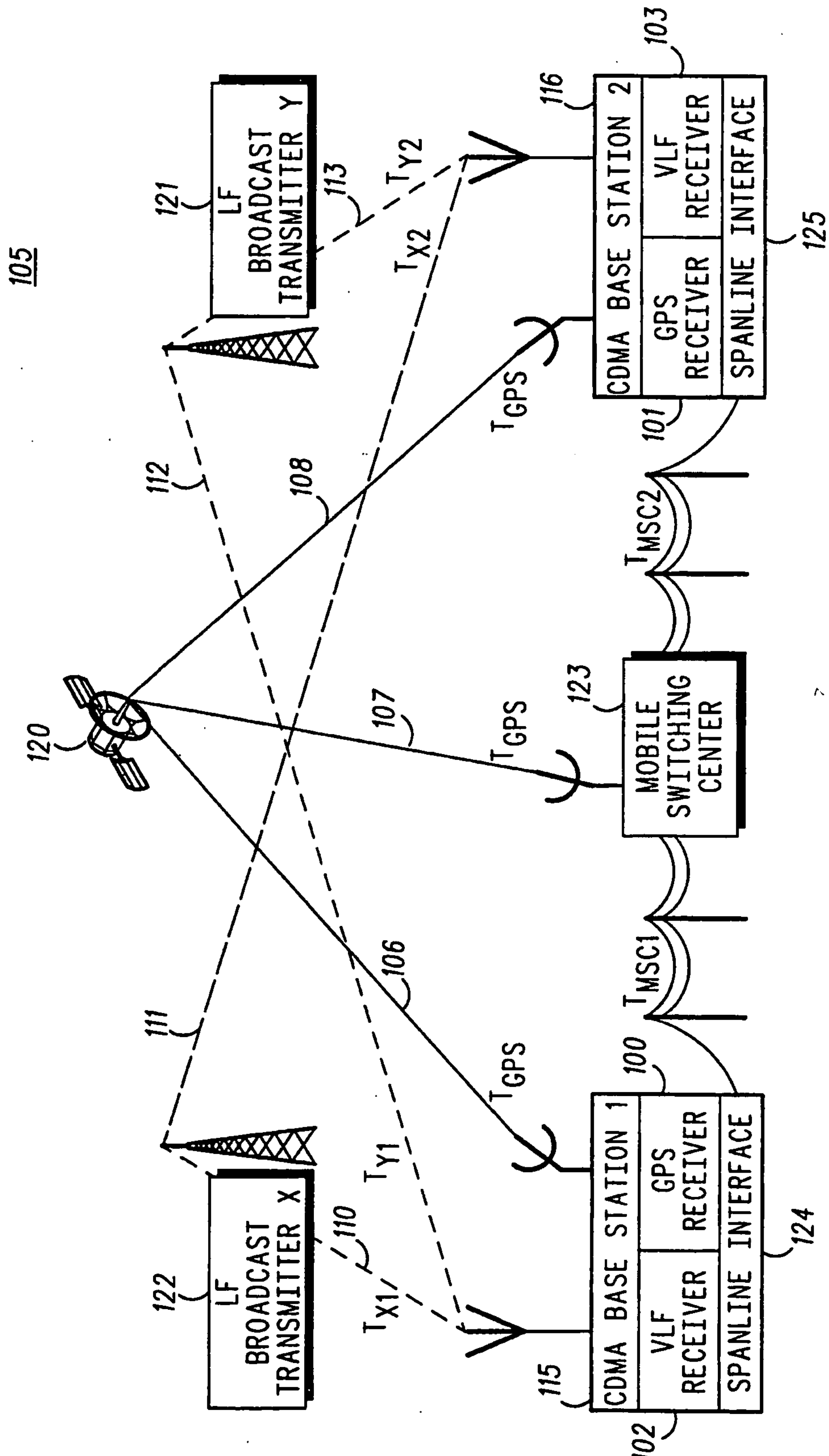
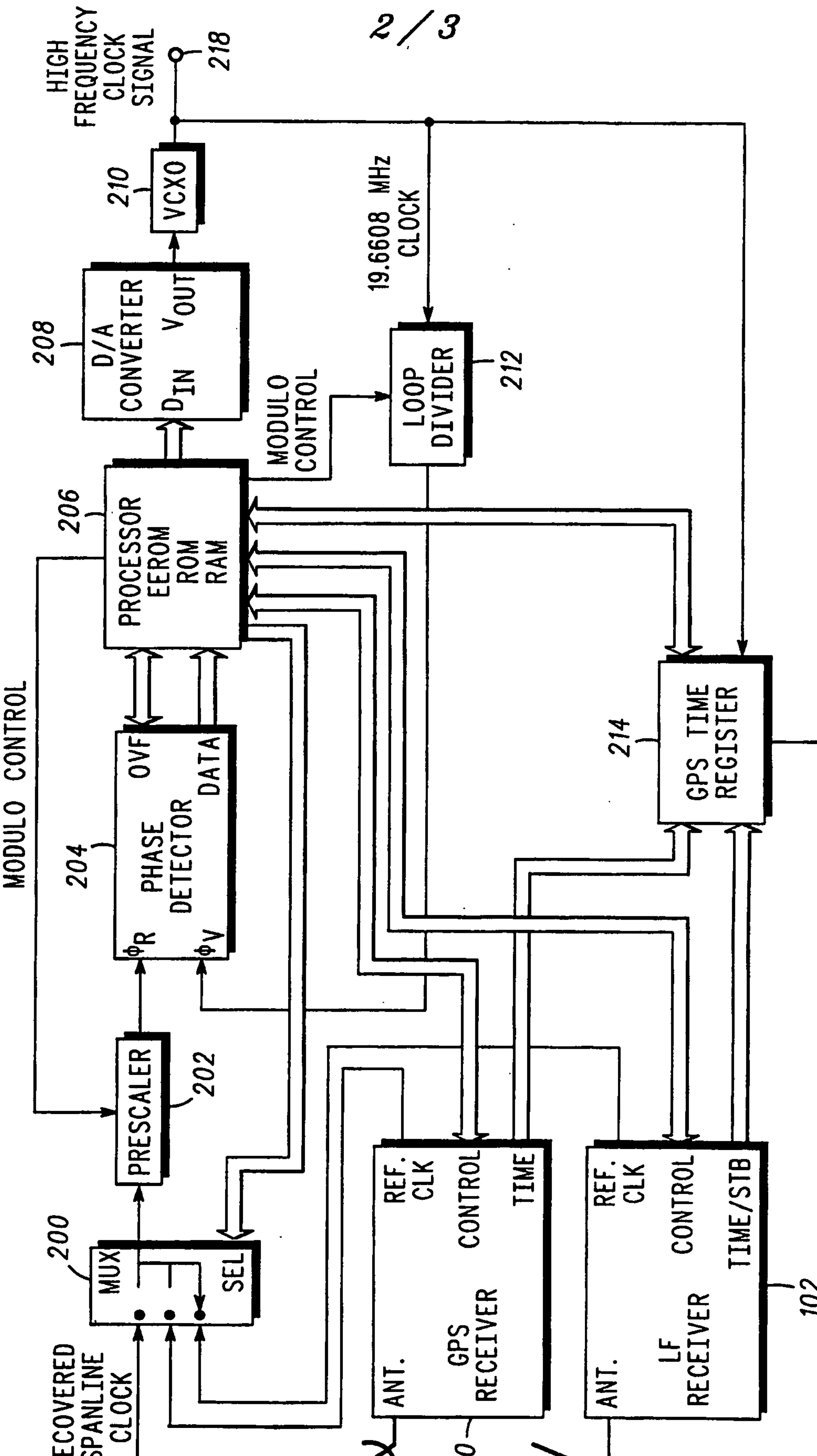

105
LF BROADCAST TRANSMITTER Y
121
113
T_{Y2}
T_{X2}
CDMA BASE STATION 2
GPS RECEIVER
VLF RECEIVER
SPANLINE INTERFACE
116
103
101
125
T_{GPS}
112
108
T_{MSC2}
120
107
T_{GPS}
MOBILE SWITCHING CENTER
123
T_{MSC1}
111
106
T_{GPS}
LF BROADCAST TRANSMITTER X
122
110
T_{Y1}
T_{X1}
CDMA BASE STATION 1
VLF RECEIVER
GPS RECEIVER
SPANLINE INTERFACE
100
115
102
124

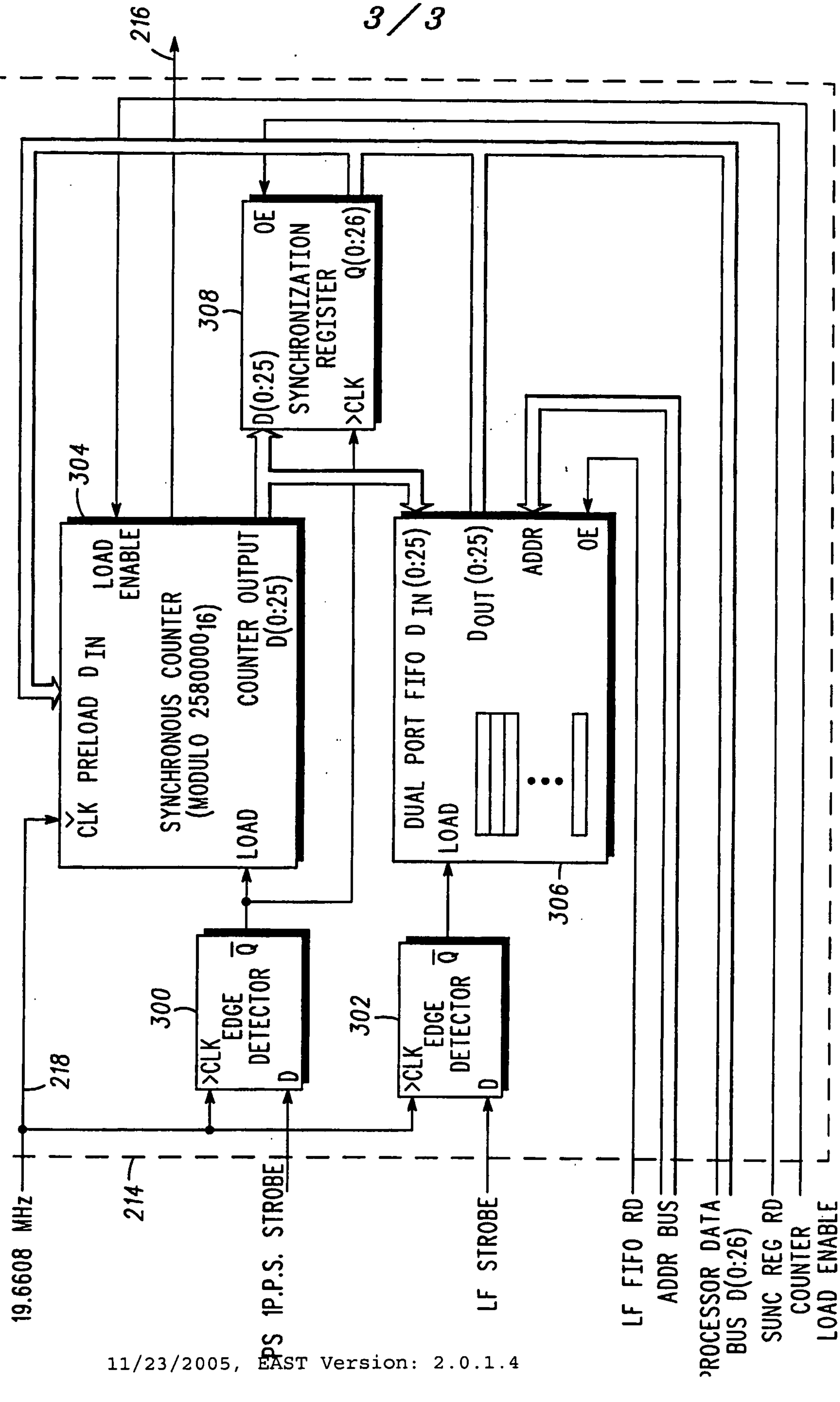
FIG.1

2/3



HIGH FREQUENCY CLOCK SIGNAL
218
210
VCXO
208
D/A CONVERTER
D_{IN}
V_{OUT}
19.6608 MHz CLOCK
MODULO CONTROL
LOOP DIVIDER
212
206
PROCESSOR EEROM ROM RAM
MODULO CONTROL
204
PHASE DETECTOR
OVF
DATA
ΦR
ΦV
SYNCHRONIZATION REFERENCE SIGNAL
216
214
GPS TIME REGISTER
202
PRESCALER
200
MUX
SEL
REF. CLK
CONTROL
TIME
ANT.
GPS RECEIVER
REF. CLK
CONTROL
TIME/STB
ANT.
LF RECEIVER
102
RECOVERED SPANLINE CLOCK

FIG. 2



216
308
SYNCHRONIZATION REGISTER
OE
Q(0:26)
D(0:25)
>CLK
304
LOAD ENABLE
CLK PRELOAD D IN
SYNCHRONOUS COUNTER
(MODULO 2580000 16)
COUNTER OUTPUT
D(0:25)
LOAD
DUAL PORT FIFO D IN (0:25)
D OUT (0:25)
ADDR
OE
LOAD
306
300
>CLK
EDGE DETECTOR
D
Q
302
>CLK
EDGE DETECTOR
D
Q
218
214
19.6608 MHz
PS 1P.P.S. STROBE
LF STROBE
LF FIFO RD
ADDR BUS
PROCESSOR DATA BUS D(0:26)
SUNC REG RD
COUNTER LOAD ENABLE

FIG. 3

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US93/08970

A. CLASSIFICATION OF SUBJECT MATTER
IPC(5) :Please See Extra Sheet.
US CL :455/12.1, 13.2, 51.1
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED
Minimum documentation searched (classification system followed by classification symbols)
U.S. : 455/12.1, 13.2, 33.1, 51.1, 51.2; 375/40, 108, 109; 340/825.01

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US, A, 4,979,191 (Bond et al) 18 December 1990. Col. 3, lines 45-69; Col. 4, lines 1-6; Fig. 1	1-6, 10
Y	US, A, 5,052,028 (Zwack) 24 September 1991. Col. 1, lines 8-69.	1-10
Y	WO, A, WO92/11707 (Fennell et al) 09 July 1992. Page 2, line 35; Page 3 lines 1-17	7-9

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

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Date of the actual completion of the international search 09 December 1993	Date of mailing of the international search report FEB 15 1994
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INTERNATIONAL SEARCH REPORT

International application No.
PCT/US93/08970

A. CLASSIFICATION OF SUBJECT MATTER:
IPC (5):

HO4B 7/19